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2. Patent application number
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Cambridge 3D Display Ltd, 26 Faroe Road, London W14 0EP

Patents ADP number *(if you know it)*

If the applicant is a corporate body, give the country/state of its incorporation U.K. 07631732001.

4. Title of the invention

Wide field of view projection display

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

Dr. A. Travis, Clare College, Cambridge, CB3 9AJ

Patents ADP number *(if you know it)* 07631757001.

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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a) any applicant named in part 3 is not an inventor, or
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Description	7
Claim*(s)*	
Abstract	
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Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
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Request for substantive examination *(Patents Form 10/77)*	
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11. I/We request the grant of a patent on the basis of this application.

Signature A. Travis Date 30 March 1999

12. Name and daytime telephone number of person to contact in the United Kingdom ADRIAN TRAVIS 01223 332735

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[illegible] field of view projection display

This invention relates to the field of 3D displays, head mounted displays and projection displays and is a way of increasing their field of view.

Projection displays conventionally comprise a two dimensional array of light emitters and a projection lens. The lens forms an image of the array at some plane in space, and if this imaging plane is far from the projection lens then the effect of the projection lens is to collimate light from any pixel on the two dimensional array.

Projection displays are most commonly directed so that the image of the array falls on a large translucent screen, and a viewer looking at the screen will see a greatly magnified image of the picture on the two dimensional array. But it is becoming increasingly common for small projection displays to be mounted on the head of the viewer so that the projection display is directed towards the viewer's eye, and light collimated by the projection lens from a single pixel on the two dimensional array of light emitters is subsequently focused by the viewer's cornea onto the viewer's retina so that the viewer sees an apparently distant image often known as a virtual image.

It is also possible for a large diameter projection display to be placed behind a liquid crystal display or some other spatial light modulator in order to synthesise a three dimensional image[1]. One pixel at a time of the two dimensional array of light emitters is illuminated, and an appropriate view of a three dimensional object is simultaneously displayed on the liquid crystal display such that the view of the three dimensional object is only visible if observed from the direction in which the rays of light collimated by the projection lens from the pixel are travelling. A sequence of views is repeated at a rate faster than that at which the eye can detect flicker, thereby time-multiplexing a three dimensional image. It is furthermore possible in principle to create a holographic three dimensional image by placing a two dimensional array of point source light emitters in the focal plane of the projection lens, illuminating each point source in turn, and displaying appropriate holograms on a liquid crystal display placed on top of the projection lens so that each hologram is made visible to a different point of view in turn.

Head mounted displays are bulky and users would prefer that they were flat. A head mounted display can be made flatter using a slab waveguide incorporating a weak hologram[2]. Light from a cathode ray tube and hologram can be coupled into the waveguide, and this light will be diffracted out of the waveguide by the hologram in directions which are determined by the pixel within the cathode ray tube from which the light was emitted.

Three dimensional images synthesised by time-multiplexing the illumination of a liquid crystal display require the liquid crystal display to have a fast-switching array of thin film transistors and these are expensive. Trayner and Orr have demonstrated a device which avoids this by placing a hologram behind a conventional liquid crystal display that directs the illumination of alternate rows to a left-eye or right-eye view[3]. But both this and the switched illumination concept are bulky, and users would prefer that three dimensional displays were flat.

Instead a flat panel three dimensional display can be made by combining a projection display with a screen on which light shone parallel to the surface of the screen is ejected at one of a set of selectable lines along the screen[4]. One line at a time on the screen is selected, and simultaneously the projection display projects a line of pixels parallel to the screen so that they are ejected at the selected line. The same line of pixels on the projection display is altered repeatedly as each of the series of lines on the screen is selected in turn in such a way as to time-multiplex a complete image on the screen. Only one line of the projection display is used, so the array of light emitters need be only one line high, and if the emitted light is collimated in the plane of the screen then the projection lens need be only one or two millimetres high so that the combined projector and screen are flat.

If it is light from a three dimensional display, albeit one whose array of light emitters is only one pixel high, which is directed parallel to the surface of the screen of selectable lines, then the image formed on the screen is three dimensional. The three dimensional display might comprise an array of light emitters behind a projection lens with a liquid crystal display in front of the projection lens, as described above, but in order to put up several views within one line period of the display, the switching rate of the liquid crystals would need to equal the number of views times the line rate of the display and few liquid crystal mixtures switch this fast.

Many other kinds of autostereoscopic and holographic three dimensional display concepts exist and any could be used in a flat panel system. Particularly interesting is an old concept comprising a group of small video projectors in the focal plane of a field lens. Each projector is positioned to form a view in the plane of the field lens just as if the lens were a translucent screen, but unlike a translucent screen the field lens collimates the light so that the picture is visible from only a single direction. The other projectors form views which are made visible by the field lens to other directions so that the viewer sees an autostereoscopic three dimensional image.

The problem with this concept is that it is difficult to design a projection lens whose pupil equals the lens' physical diameter, so there are gaps between the video projectors which form dark zones between each view of the three dimensional image. A slightly diffusive element can be used to eliminate these gaps, but the angle of diffusion usually varies with incident light angle. Aberrations in the field lens mean that rays collimated by the lens from a single point hit the diffusion screen at slightly different angles of incidence. This means that the angles of diffusion vary, and even though the variance is slight it is enough to cause observable gaps or overlaps between views.

A major problem with three dimensional displays and head mounted displays in particular is that their field of view is limited by the aberration of the projection lens. At fields of view beyond 20° the lens collimates light so poorly that the image is too distorted for most applications.

According to the present invention there is provided a wide field of view projection display comprising a circularly symmetric lens, sometimes called a monocentric lens, and a curved array of light emitters whose centre of curvature is at the centre of the

circularly symmetric lens and which is placed at or near the focal plane of the circularly symmetric lens.

A specific embodiment of the invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 illustrates a wide field of view projection display

Figure 2 illustrates a wide field of view multiple projector autostereoscopic three dimensional display where the screen is only one pixel width high.

Figure 3 illustrates a flat panel wide field of view autostereoscopic three dimensional display with a screen on which light shone parallel to the surface of the screen is ejected at one of a set of selectable lines along the screen

Figure 4 illustrates how a diffuser is used to eliminate the gaps between adjacent views on a wide field of view three dimensional display.

Figure 5 illustrates how without anticipatory correction, rays from an off-axis microdisplay on a wide field of view three dimensional display will produce a view distorted by shear.

Figures 6a and 6b illustrate how a pair of mirrors fold rays from opposite off-axis microdisplays so that rays folded from one microdisplay fill in the gaps of a view left by rays from the opposite microdisplay.

Referring to the drawings the projection display of Figure 1 comprises a circularly symmetric lens (1) and an array of light emitters (2) which is curved so that each of the light emitters (2) lies in the focal plane of the circularly symmetric lens (1). The circularly symmetric lens (1) comprises a series of concentric coplanar transparent annuli whose refractive indices are chosen so that the lens (1) collimates light from any point on the focal plane, and between the edges of each adjacent annuli a conventional anti-reflection coating may be applied. For example a disc of polymethylmethacrylate of radius 50 mm inside an annulus of polycarbonate of internal radius 50 mm and external radius 100 mm will collimate light from any point on a focal plane of radius 172 mm. Alternatively the circularly symmetric lens (1) may comprise a graded index disc whose refractive index varies with radius and is largest at the centre. A second alternative is that the circularly symmetric lens (1) may comprise a disc of material whose thickenss varies with radius. Light from the array of light emitters (2) is injected into the edge of the disc at a single angle to the disc axis so that the surfaces of the disc behave like a slab waveguide and guides light by total internal reflection from one edge to the other. The disc becomes thicker towards the centre, and as rays are guided into thicker parts of the disc the angle between ray direction and the axis of the disc becomes smaller. The resolved part of ray direction in the plane of the disc therefore becomes smaller, so the rays take longer to travel through the centre of the disc than the edges. The disc therefore collimates light in much the same way as a graded index lens.

In the autostereoscopic three dimensional display of Figure 2, each light emitter in the curved array of light emitters (2) comprises a small lens (3) illuminated by light reflected off a microdisplay (4) in the focal plane of the small lens (3).

In Figure 3, light from the combination of circularly symmetric lens (1), small lens (3), and microdisplay (4) is shone parallel to the surface of a sheet of reflective foil (5) and a transducer (6) at one end of the sheet of foil (5) sets up a single surface wave (7) which travels the length of the foil (5) and which reflects the injected light at different lines along the foil (5) as the surface wave (7) travels.

If we consider light from a single microdisplay (4) at a single instant, the light will be modulated by the microdisplay (4), expanded by the small lens (3) and collimated by the circularly symmetric lens (1) to produce a series of parallel rays travelling parallel to the sheet of foil (5). When this light hits the surface wave (7) the light will be ejected from the screen in a particular direction, and if a viewer observes the foil (5) from that direction the viewer will see a line of pixels visible at the surface wave (7). In successive instants as the surface wave (7) moves down the sheet of foil (5), lines of pixels can be made visible at other positions on the sheet of foil (5), and if this is repeated sufficiently quickly the viewer will see a time-multiplexed two dimensional image.

In a similar manner other microdisplays (4) can be modulated to produce other two dimensional images on the sheet of foil (5), but each two dimensional image will be visible from a different direction. If each two dimensional image is a view of what the viewer would see were there to be a three dimensional object in place of the sheet of foil (5), then the image seen by the viewer would appear to be three dimensional with one important proviso. As the viewer moves the head from side to side, the viewer will see different views of the three dimensional image, but there will be gaps between each view where the viewer can see nothing because the field of view of each two dimensional image in the system so far described is so narrow. The solution to this is to add a diffuser (8) as shown in Figure 4, comprising a grating or screen of lenslets which expands the field of view of each two dimensional image so that there are no gaps between adjacent views.

Diffusers, like lenses, suffer from aberrations in the sense that rays travelling from different angles are diffused by slightly different amounts. But because the circularly symmetric lens has no aberrations, the light for each view is properly collimated, so all the rays which comprise the view are diffused by the same amount. It is therefore possible to close the gap between each pair of adjacent views by moving the relevant microprojectors (4) without there being any overlap, even at extreme angles of view.

A problem arises in that at extreme angles of view, the rays on one side go over the edge of the sheet of foil (5) before hitting the surface wave (7), while the rays on the other side leave an increasingly large part of the surface wave (7) unilluminated as shown in Figure 5. The picture is distorted, and a dark triangular gap appears at the top of each off-axis view. The distortion can be anticipated and corrected by digital pre-processing of the image in a frame-store, and digital pre-processing can also be used to eliminate the triangular gaps provided that a pair of mirrors (9) are added to the system.

The pair of mirrors (9) are placed at either side of the sheet of foil as shown in Figures 6a and 6b so that the rays going over the edge of the sheet of foil (5) are reflected back. These reflected rays will now become part of the opposite view to that formed by unreflected rays, but in doing so the reflected rays fill in the gap left in the opposite view by the rays in that opposite view leaving part of the surface wave (7) unilluminated. It is then a matter merely of swapping pixels in the frame store to ensure that the right pixels end up on the right position on the screen.

Further embodiments of the invention are now described with reference to the accompanying drawings in which:

Figure 7 illustrates a wide field of view flat panel projection display.

Figure 8 illustrates a holographic wide field of view flat panel display.

Figure 9 illustrates how a pair of mirrors and a one-dimensional retroreflector can keep illumination uniform even at large off-axis angles.

Figure 10 illustrates a wide field of view three dimensional flat panel display using a light valve.

Figure 11 illustrates a holographic wide field of view flat panel display which needs no thin film transistors.

Figure 12 illustrates a wide field of view flat panel head mounted display.

If collimated light is injected into a slab waveguide and a weak diffraction grating is embossed on one surface of the slab waveguide then the grating will diffract some of the light out of the waveguide. The direction in which the diffracted light leaves the waveguide will be determined by the initial direction of the injected light, so that by modulating the intensity of light collimated into each of several directions at the input to the waveguide, one can control the intensity of light being diffracted out by the grating, and this can be used to project an image.

Figure 7 shows how light is injected into a slab waveguide (10) from a wide field of view projection display comprising a circularly symmetric lens (1) and an array of light emitters (2). Light from each pixel of the array of light emitters (2) is collimated by the circularly symmetric lens (1) into a particular direction, and this is coupled into the slab waveguide (10) and diffracted out from all of one surface of the slab waveguide (10) by the weak diffraction grating (11) so as to cause collimated light to travel in a particular direction. Other pixels of the array of light emitters (2) cause light to be diffracted by the weak diffraction grating (11) in other directions, and the result is the projection of an image from a flat panel.

A three dimensional display can be created by placing a fast switching liquid crystal display (12) over a large projection display, and figure 8 illustrates how a wide field of view flat panel three dimensional display can be created by placing a fast switching

liquid crystal display (12) over a wide field of view flat panel projection display. The image can be either autostereoscopic (in which case pixels in the array of light emitters (2) should abut) or holographic (in which case pixels in the array of light emitters (2) should be point sources).

At extreme angles light from the wide field of view projection display in figure 7 may miss the slab waveguide (10). Figure 9 shows how a pair of mirrors (9) and a one-dimensional retroreflector (13) can be used both to fold the optical system and to ensure that light is injected into all of the slab waveguide (10) even at wide fields of view. Light which would otherwise leave the system is reflected by one of the mirrors (9) so as to land on a one-dimensional retroreflector (13), then on an angled mirror (14). The planes of the one-dimensional retroreflector (13) and angled mirror (14) are positioned at right angles so that light is returned in the plane of the slab waveguide (10), and the prisms of the retroreflector are run perpendicular to the long axis of the retroreflector so that light returns back along the same path in the plane of the slab waveguide (10) as that on which the light travelled out in the plane of the wide field of view projector. The retroreflected light will hit the same one of the pair of mirrors (9) which it hit on its outward journey, and therefore be directed into the slab waveguide (10) at a congruent position and direction to that at which it left the circularly symmetric lens (1) of the wide field of view projector.

Fast switching liquid crystal displays can be more conveniently manufactured if they work in reflection rather than transmission. This permits for example the use of thick metal wires on the back of the display which switch quickly because they are highly conductive, but are opaque. It also permits the use of light valves (sometimes known as optically addressable spatial light modulators). Figure 10 shows how to synthesise a wide field of view three dimensional image on a light valve. Light from a wide field of view projection display is injected into the side of a slab waveguide (10), and the slab waveguide (10) incorporates a weak grating (11) but the grating (11) is blazed and volumetric so as to eject light only towards the front surface of the fast switching liquid crystal display (12). Such a grating can for example be made by gluing two sheets of 3M Image Directing Film (IDF II) face to face with a transparent glue of a slightly different refractive index to the film. Light reflected off the fast switching liquid crystal display (12) travels back through the slab waveguide (10) and on to the viewer with only minimal disruption from the grating (11) because the grating (11) is weak.

Referring to the diagram of figure 3, the sheet of foil (5) and surface wave (7) can be used to convert any one line high three dimensional display into a full flat panel three dimensional display, and the circularly symmetric lens (1) can be used to expand the field of view of most three dimensional display concepts. Figure 11 shows for example how a holographic three dimensional display with a wide field of view can be made by arranging that the array of light emitters (2) in the focal plane of the circularly symmetric lens (1) are a series of point sources, and that this combination is used to illuminate a one dimensional liquid crystal display (15). The field of view of a hologram screened on such a liquid crystal display (15) is determined by the size of its pixels, but a hologram with a wide field of view can be time-multiplexed by illuminating each of the point sources in the array of light emitters (2) and

simultaneously altering the hologram on the one dimensional liquid crystal display (15) within the time taken for the surface wave (7) to move the width of a single line. Wide fields of view are possible with such a display because the minimal aberrations of the circularly symmetric lens (1) allow the constituent holograms to be time-multiplexed without gaps or overlap.

If the same set-up is intended to display three dimensional images using autostereoscopic rather than holographic pixellation, one line of one view is shown on the liquid crystal display (15), then the equivalent line of other views can be time-multiplexed without gaps or overlap except that the array of light emitters (2) must now comprise sources of light which abut without gaps.

An important advantage of using the circularly symmetric lens (1) in the flat panel concepts so far described is that with proper design it can be stamped out of plastic in a single quick action. However circularly symmetric lenses can be made using bulk optics and the concept extended to bulk optic three dimensional displays if required.

Demand also exists for the field of view of head mounted displays to be expanded, and this could be done by providing a curved array of light emitters in the focal plane of a bulk optic circularly symmetric lens.

Figures

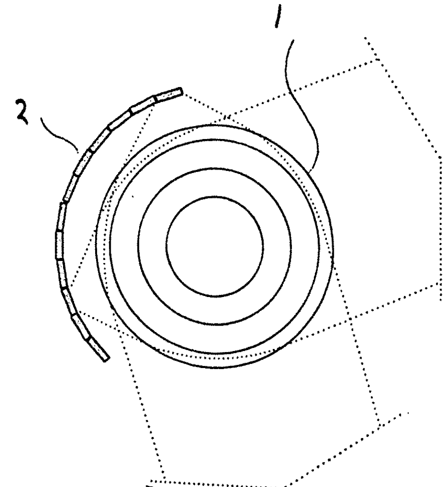

Figure 1

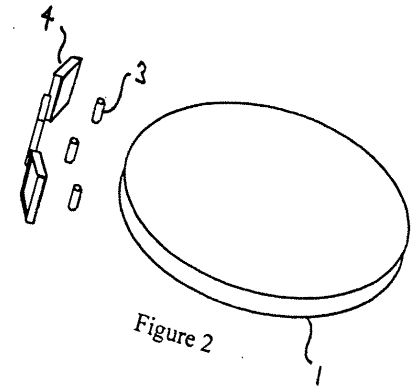

Figure 2

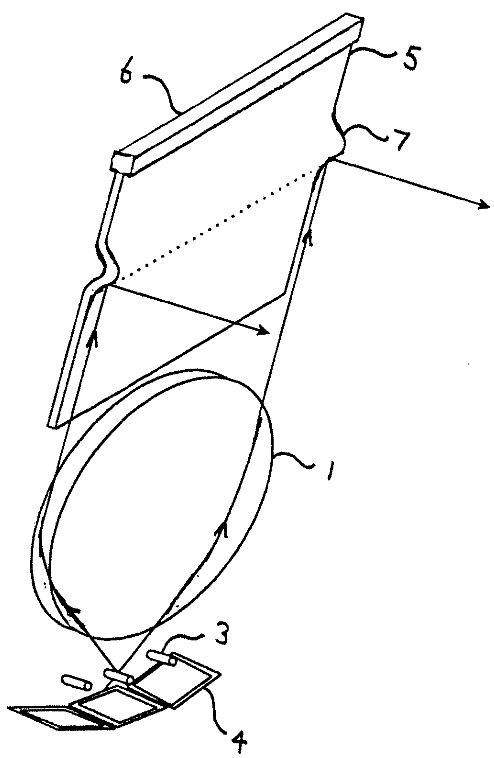

Figure 3

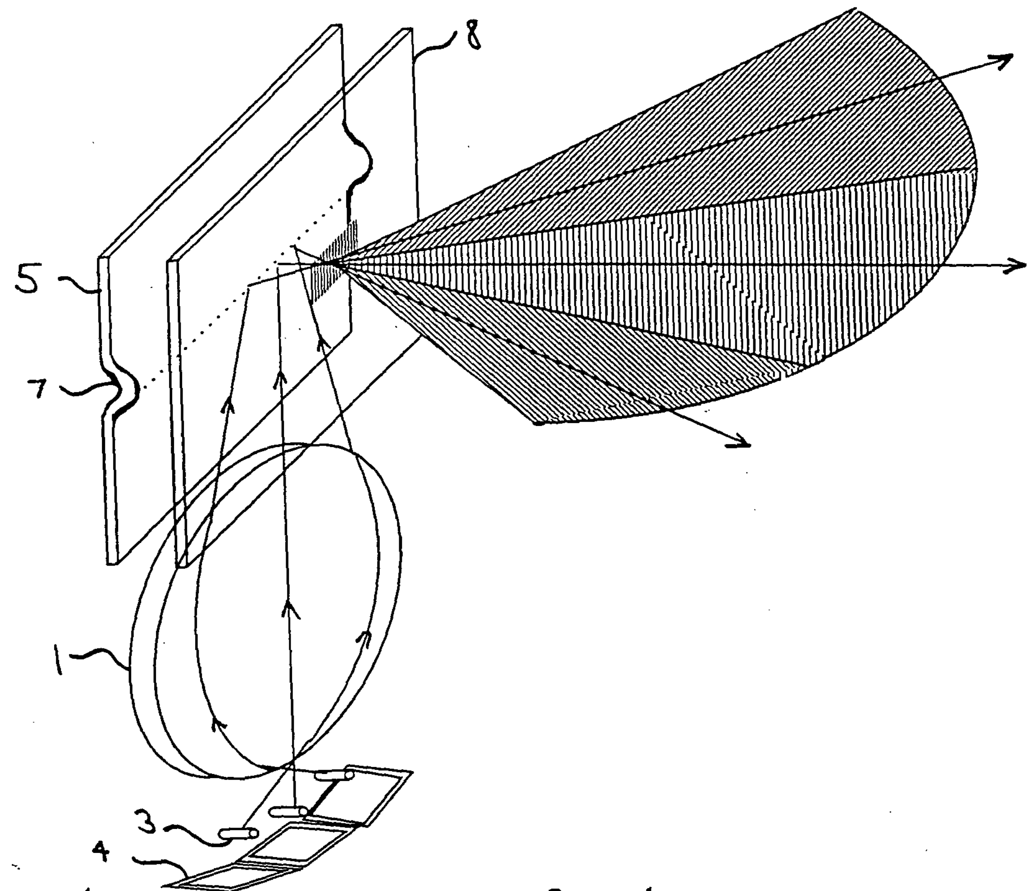

Figure 4

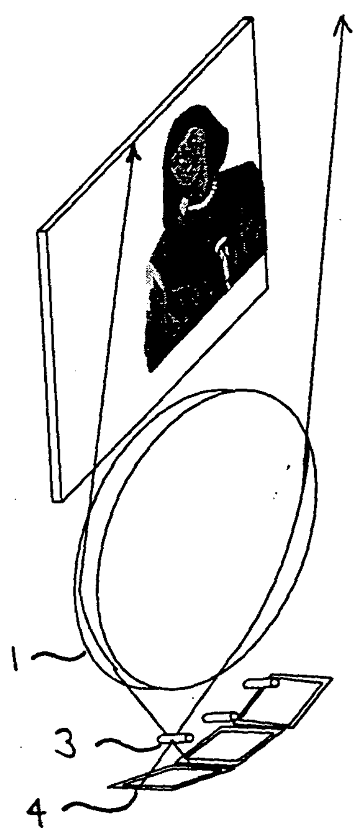

Figure 5

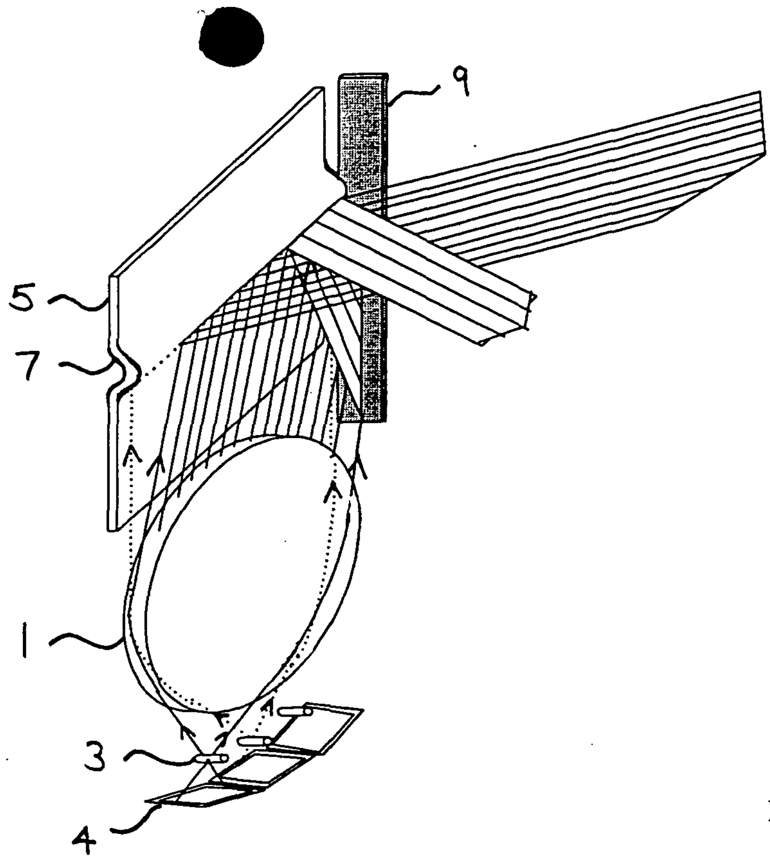

Figure 6a

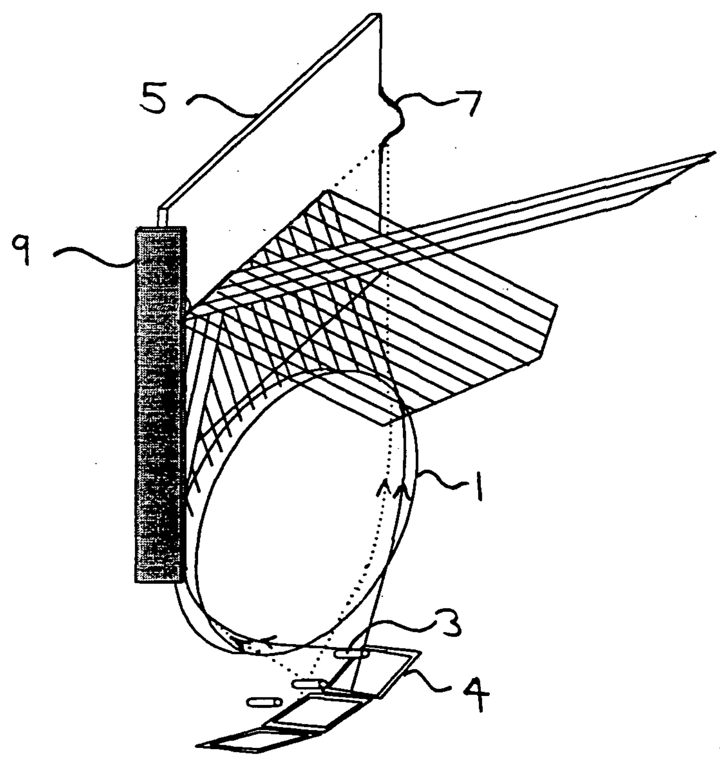

Figure 6b

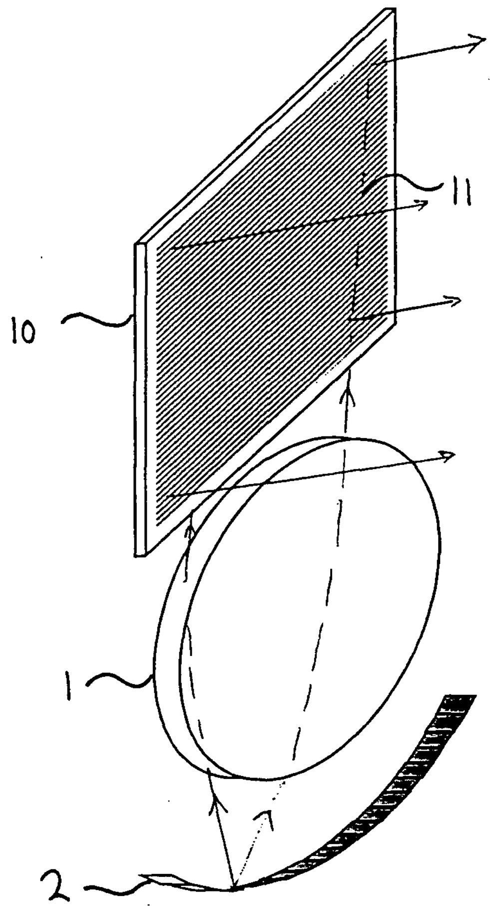

Figure 7

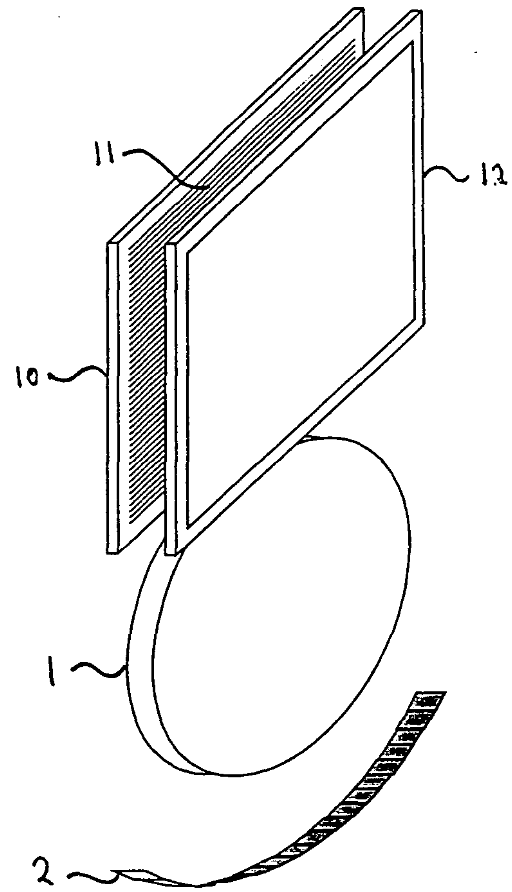

Figure 8

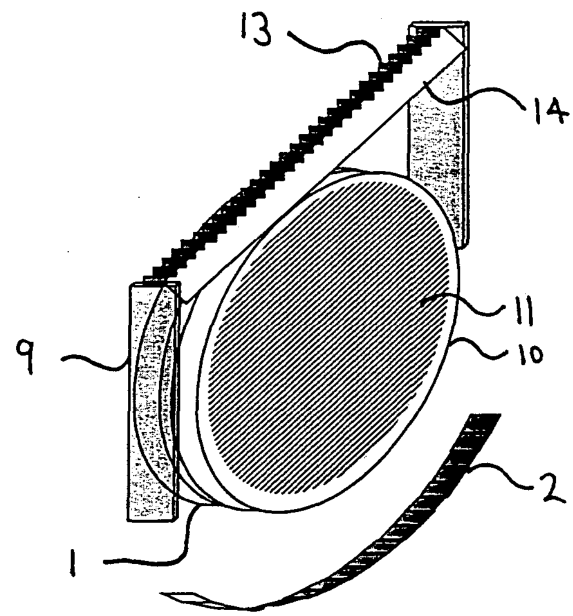

Figure 9

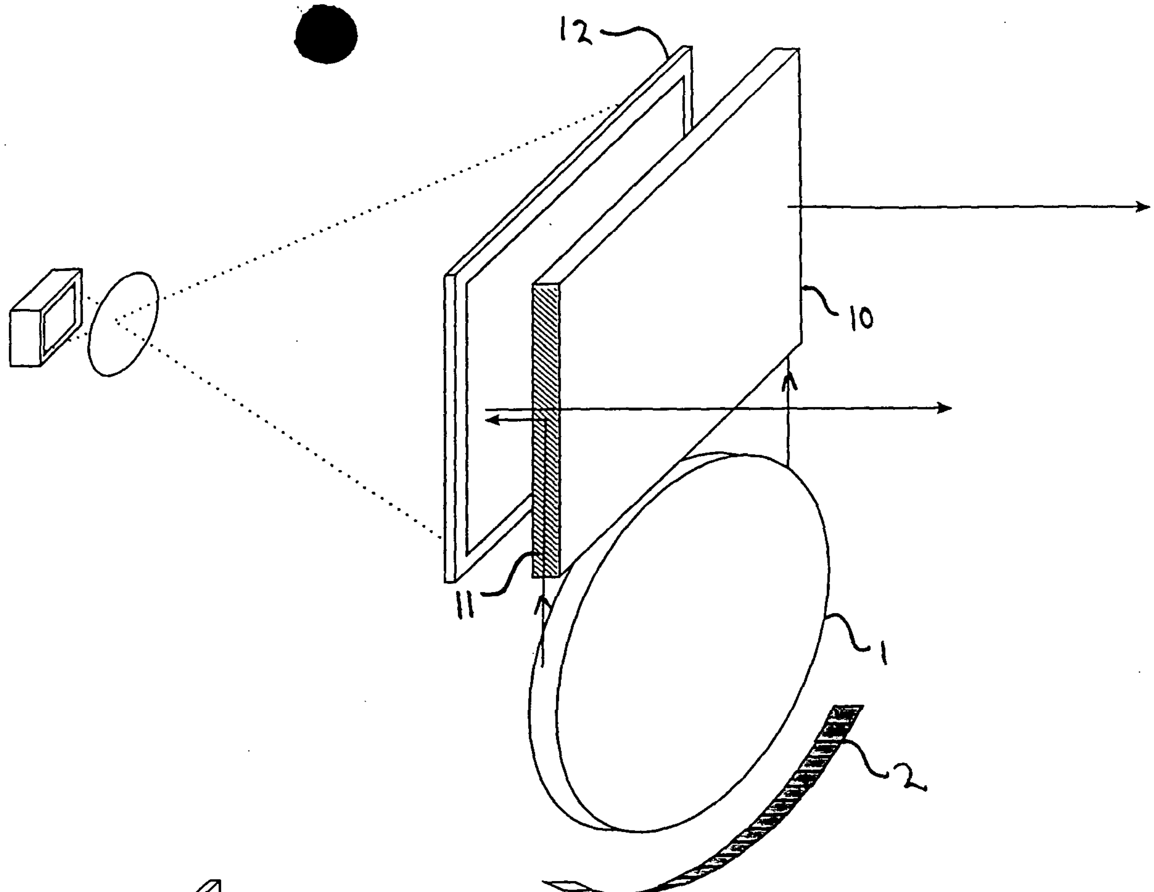

Figure 10

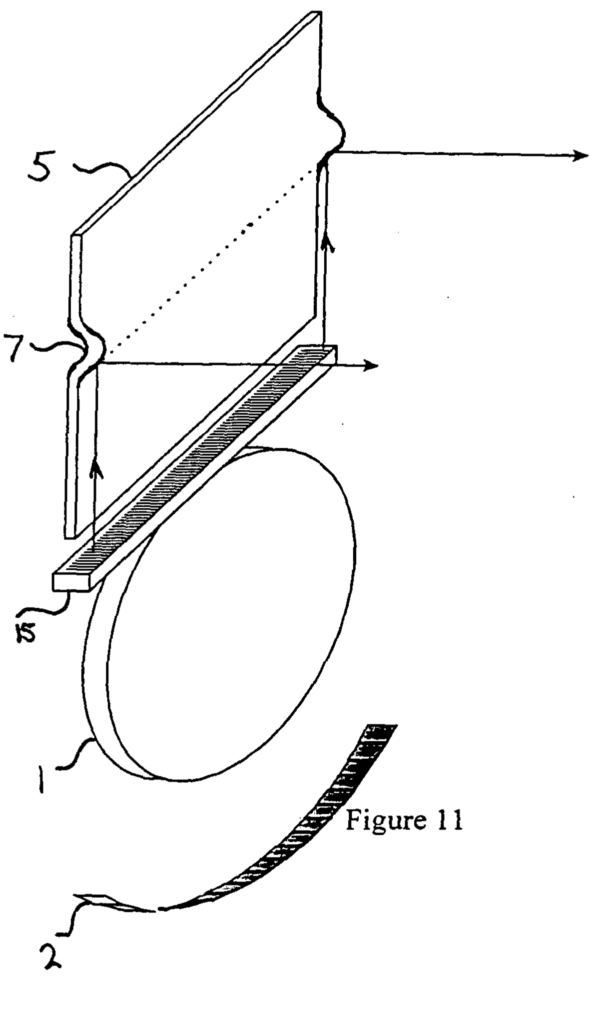

Figure 11

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